Protecting Sensitive Data in Web Browsers with ScriptPolice

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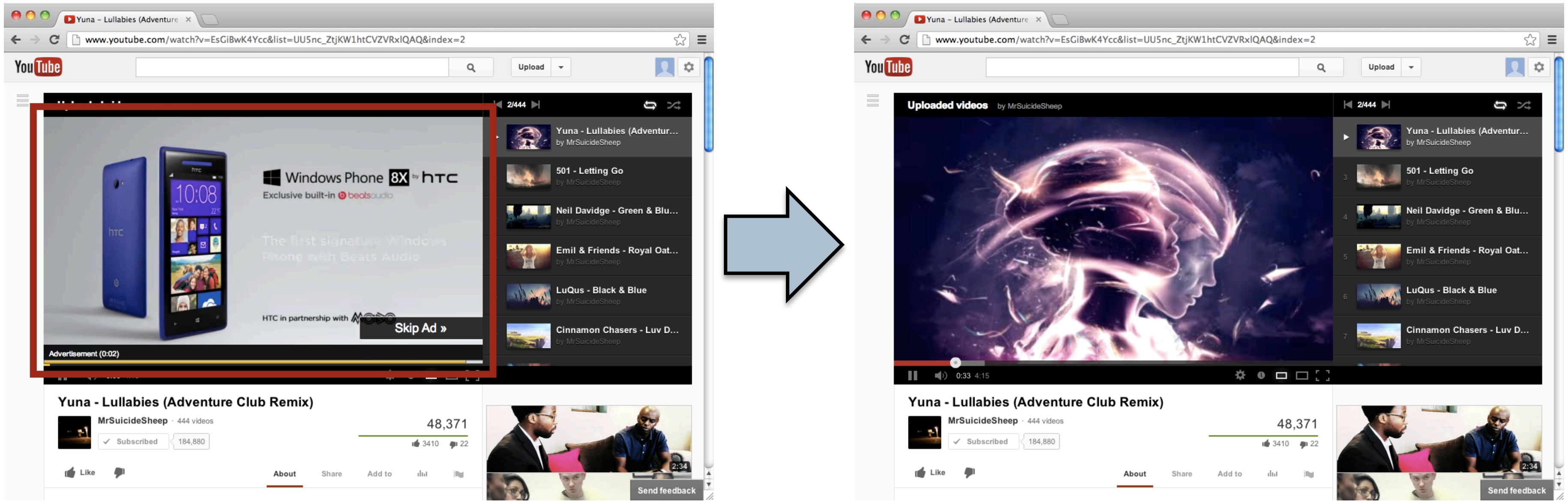
Should you trust your browser?

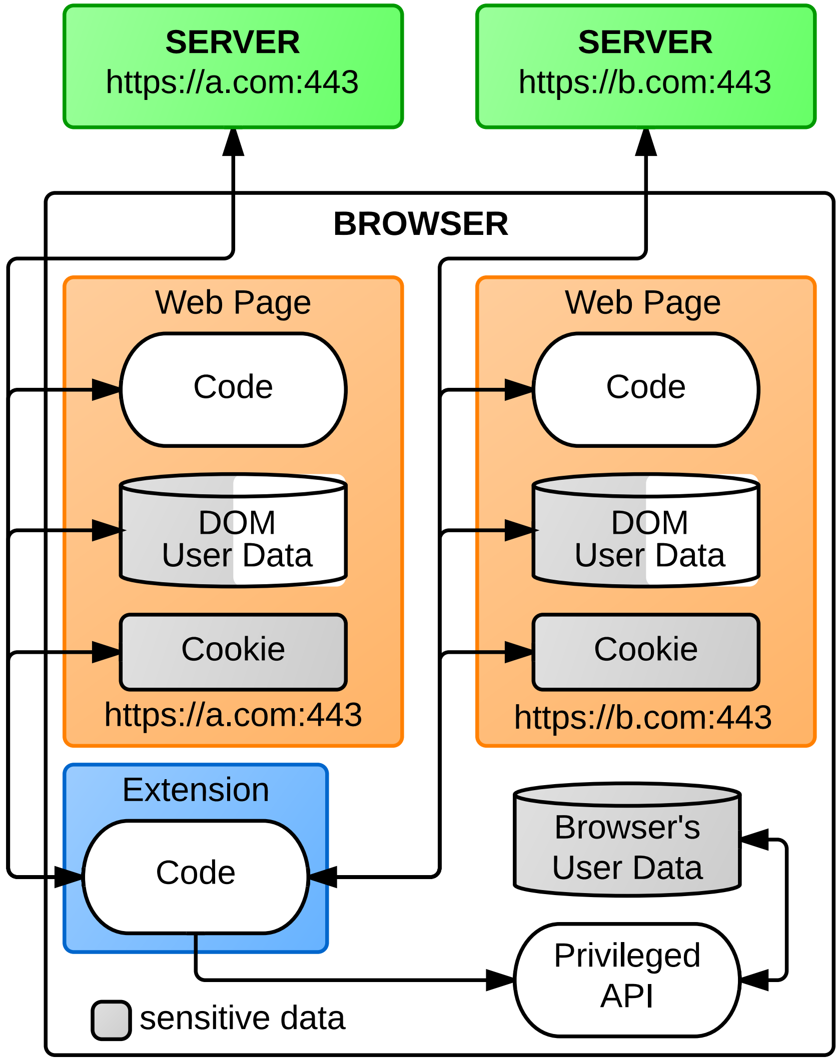
- Browsers handle sensitive data
  - e.g., email, online banking, medical records
- Browser executes untrusted JavaScript written by multiple parties
  - Pages: code written by site operators
  - Extensions: code written by third-party developers
- Potential for attacks on confidentiality
  - Pages exploit extensions
  - Extensions leak users' sensitive data from pages
- This talk:
  - These attacks are real
  - How to defend against them

Browser Primer: Extensions

AdBlock.



Browser Primer:
SOP and Extension Implementation



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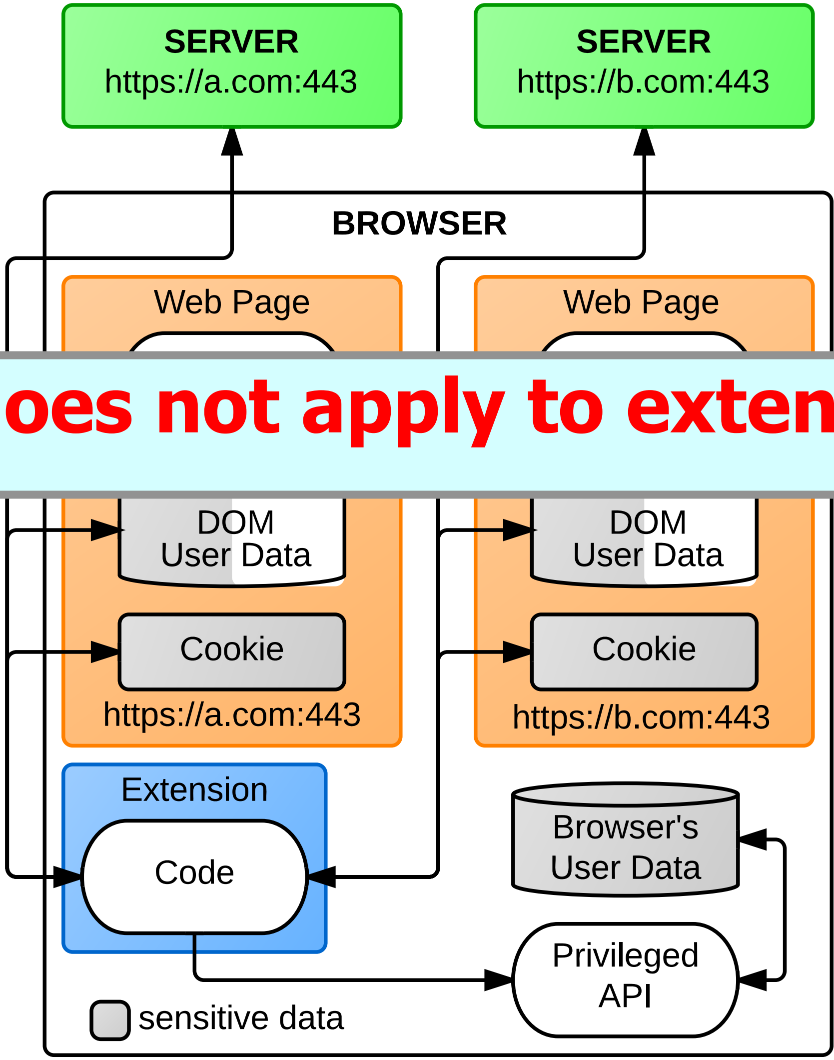
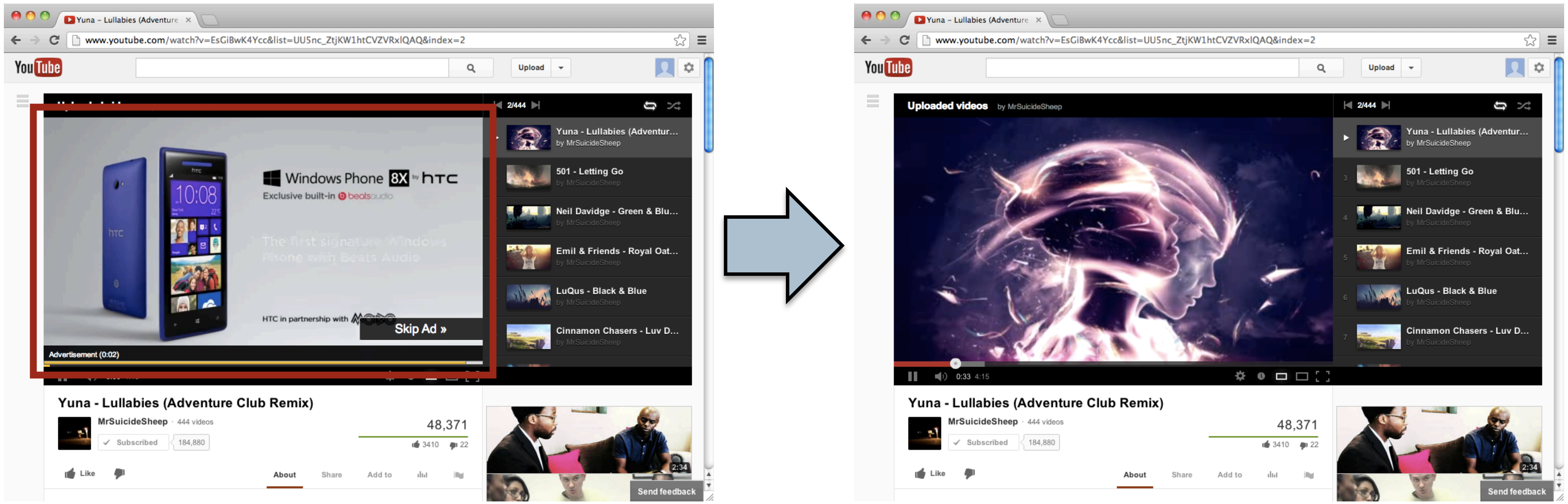


SOP does not apply to extensions

Problem: Malicious Extensions

AdBlock.



10m users

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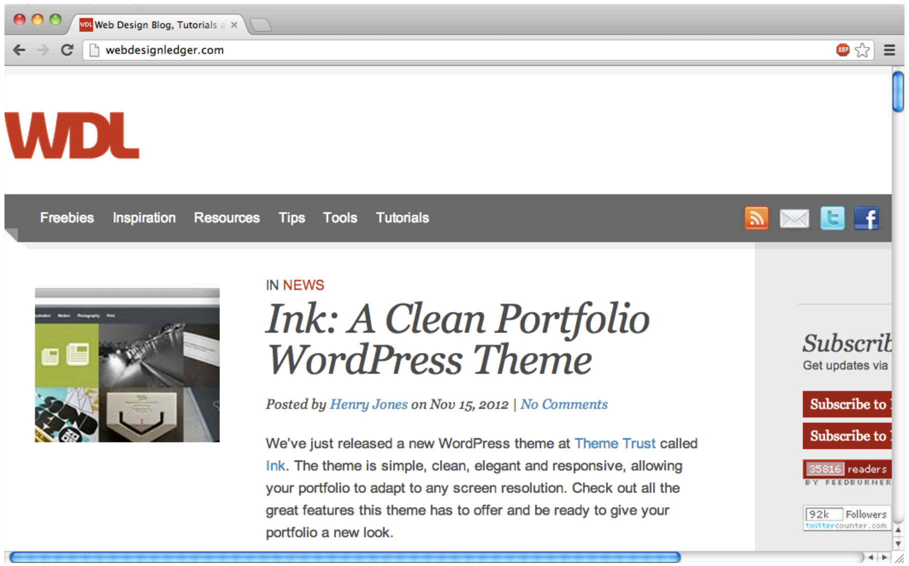

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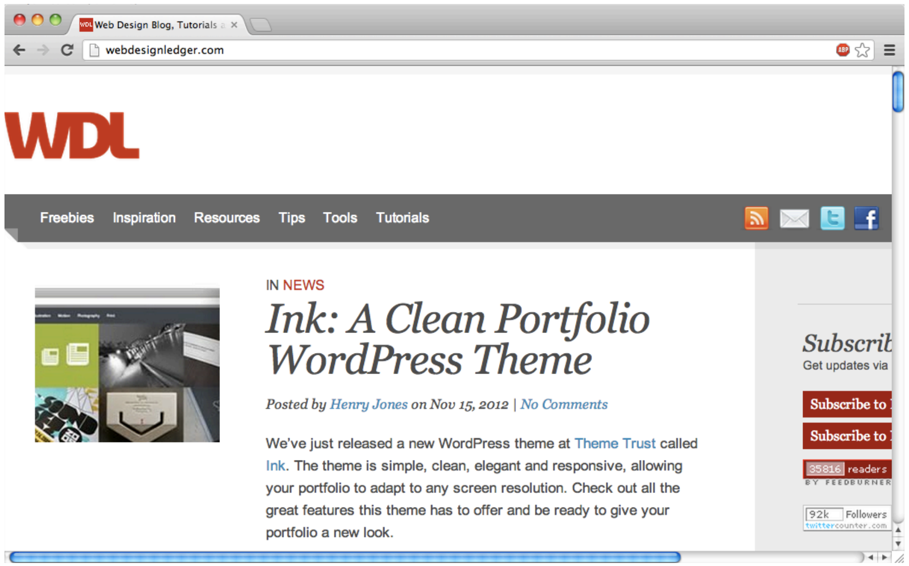

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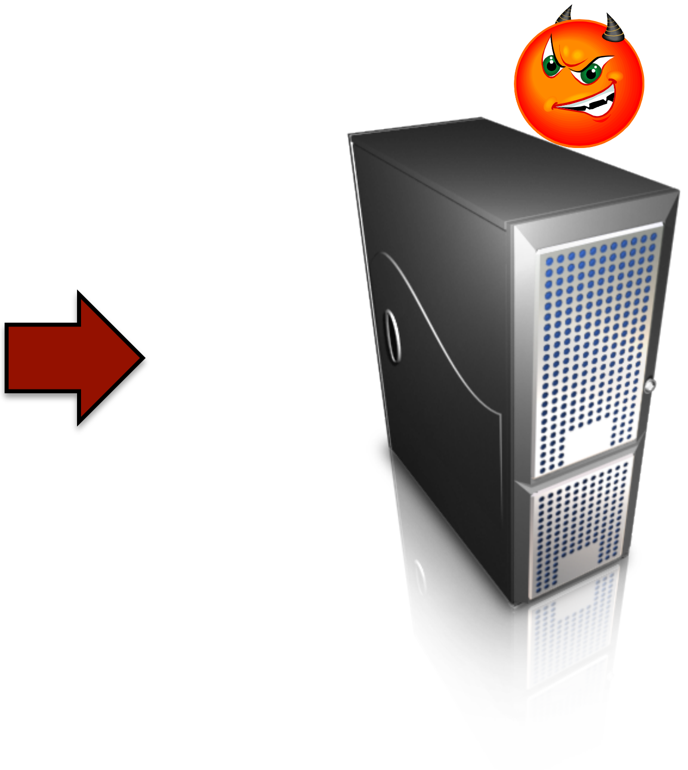
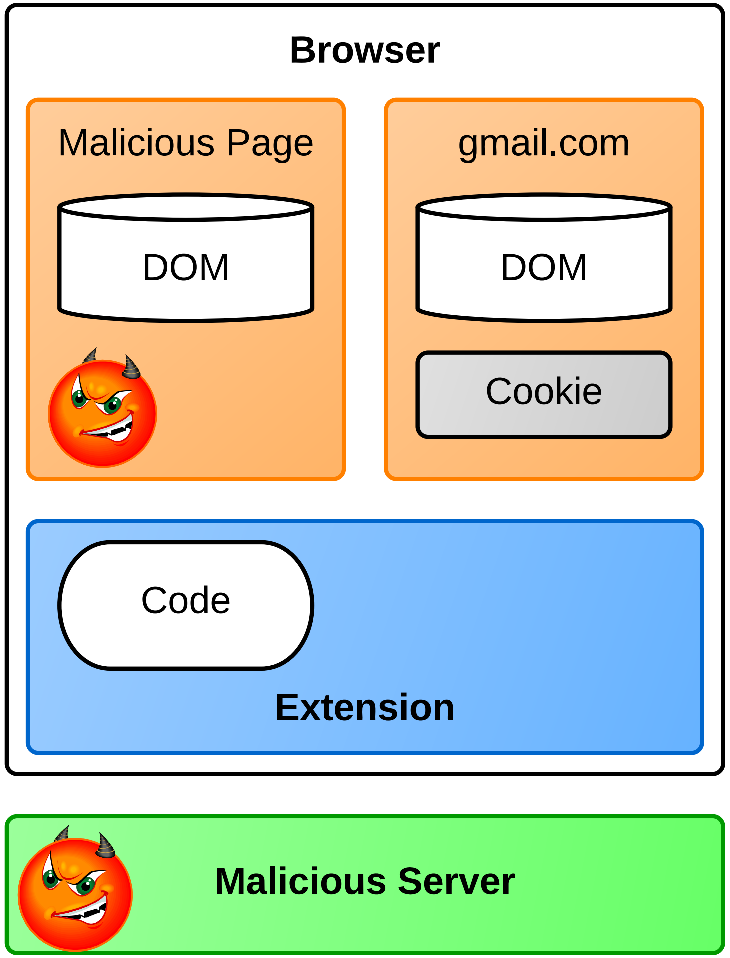


Are Extensions Vulnerable?

- We’ve found zero-day vulnerabilities in four popular Chrome extensions…
- …and designed malicious pages exploiting these extensions…

Demo: Vulnerable RSS Extension



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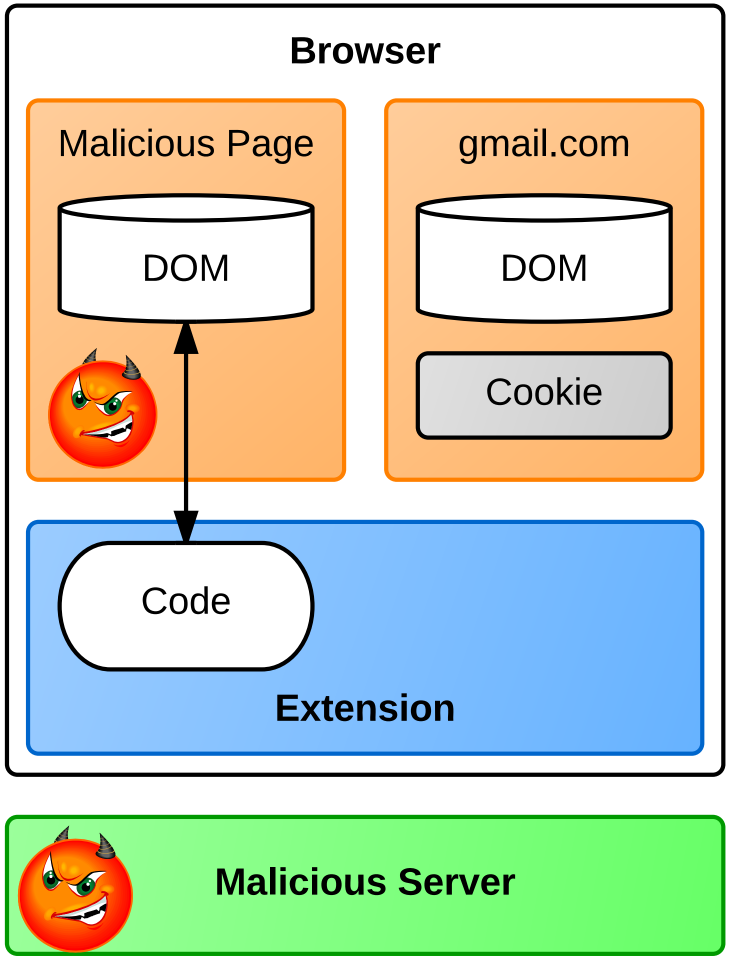

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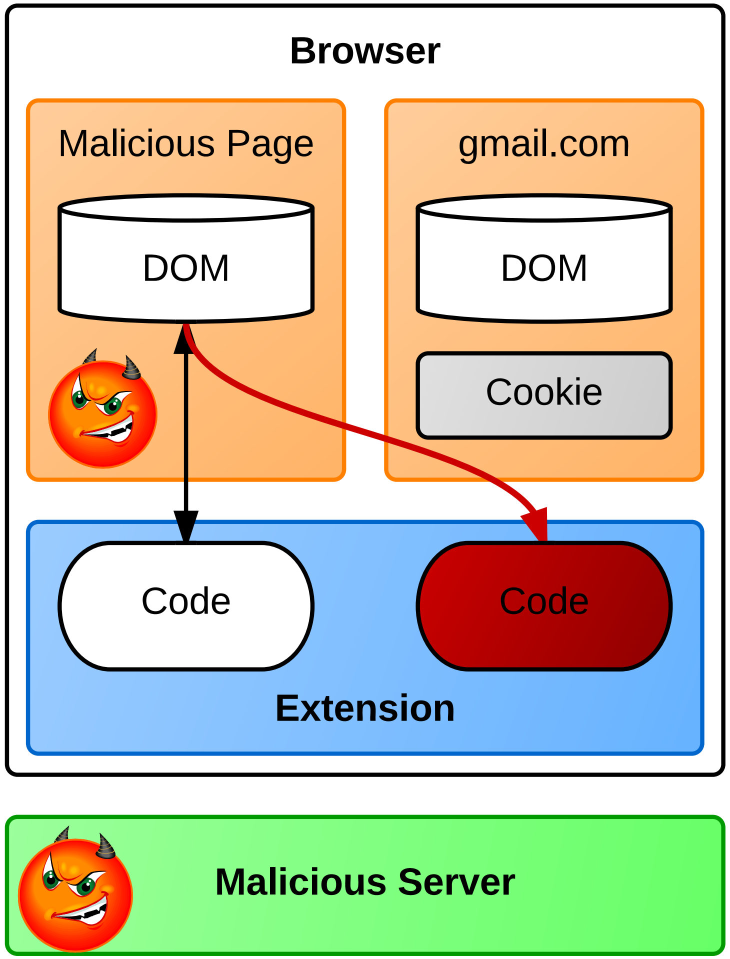

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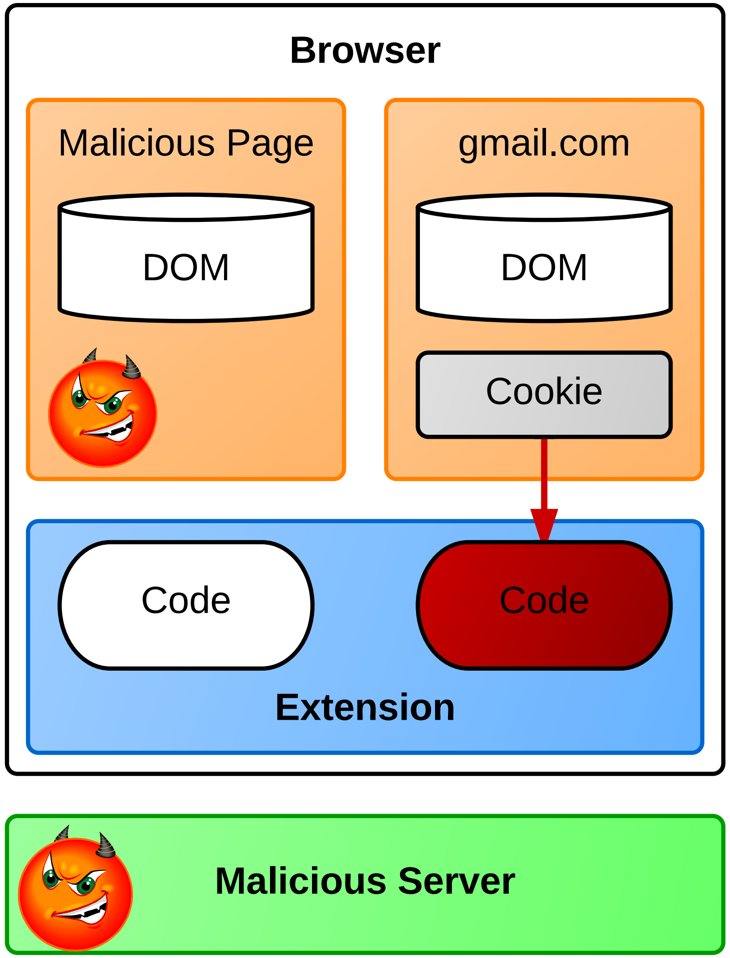

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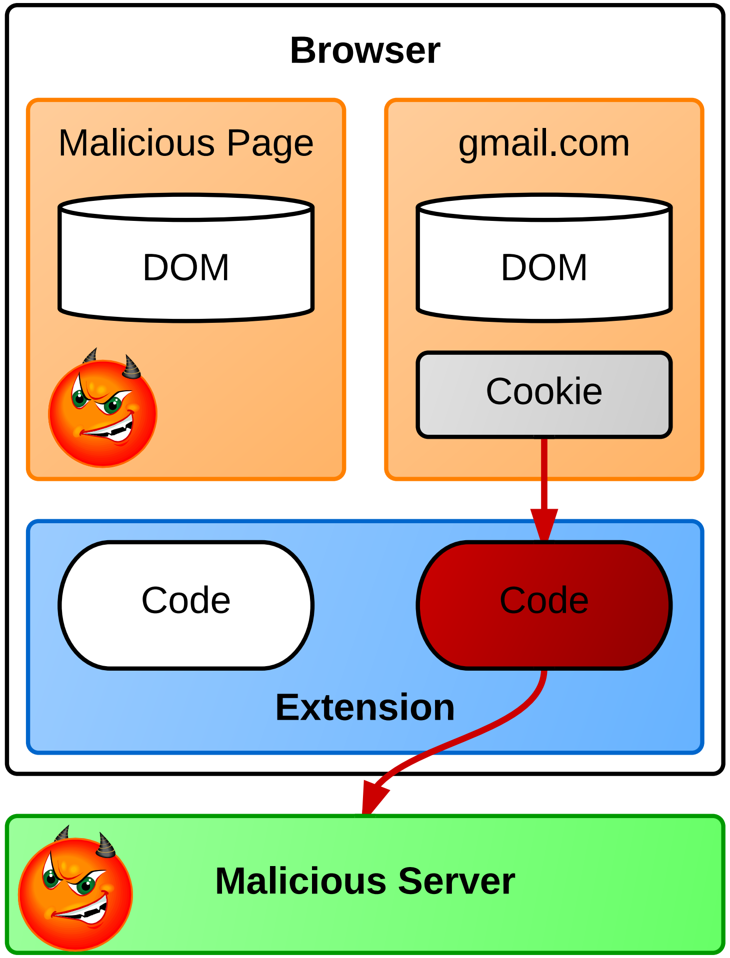

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- …and designed malicious pages exploiting these extensions…

- Carlini et al. studied 100 Chrome extensions; found 70 vulnerabilities in 40 of them

N. Carlini, A. P. Felt, and D. Wagner. An Evaluation of the Google Chrome Extension Security Architecture, USENIX Security 2012

Our Solution: ScriptPolice

- A policy system for JavaScript execution in web browsers
- Policies block exfiltration of sensitive data
- Policies are simple and general:
  - A few simple policies “baked into” browser
  - These few policies compatible with wide range of today’s extensions and pages
- Full working prototype for V8 JIT-compiled JavaScript engine in Google Chrome browser
- Performance overhead virtually imperceptible to users

ScriptPolice: System Overview

- Browser ships with a few standard policies; confines extension execution with them
  - Prevention policies block pages from injecting scripts into vulnerable extensions; implemented with information flow control (IFC)
  - Containment policies block extensions from exfiltrating sensitive data to network; implemented with discretionary access control (DAC)
- Page developers annotate sensitive page elements (e.g., bank balance, medical diagnostic test name and results)
- Extension developers declare privileges required by an extension with enhanced extension manifest

ScriptPolice: System Overview

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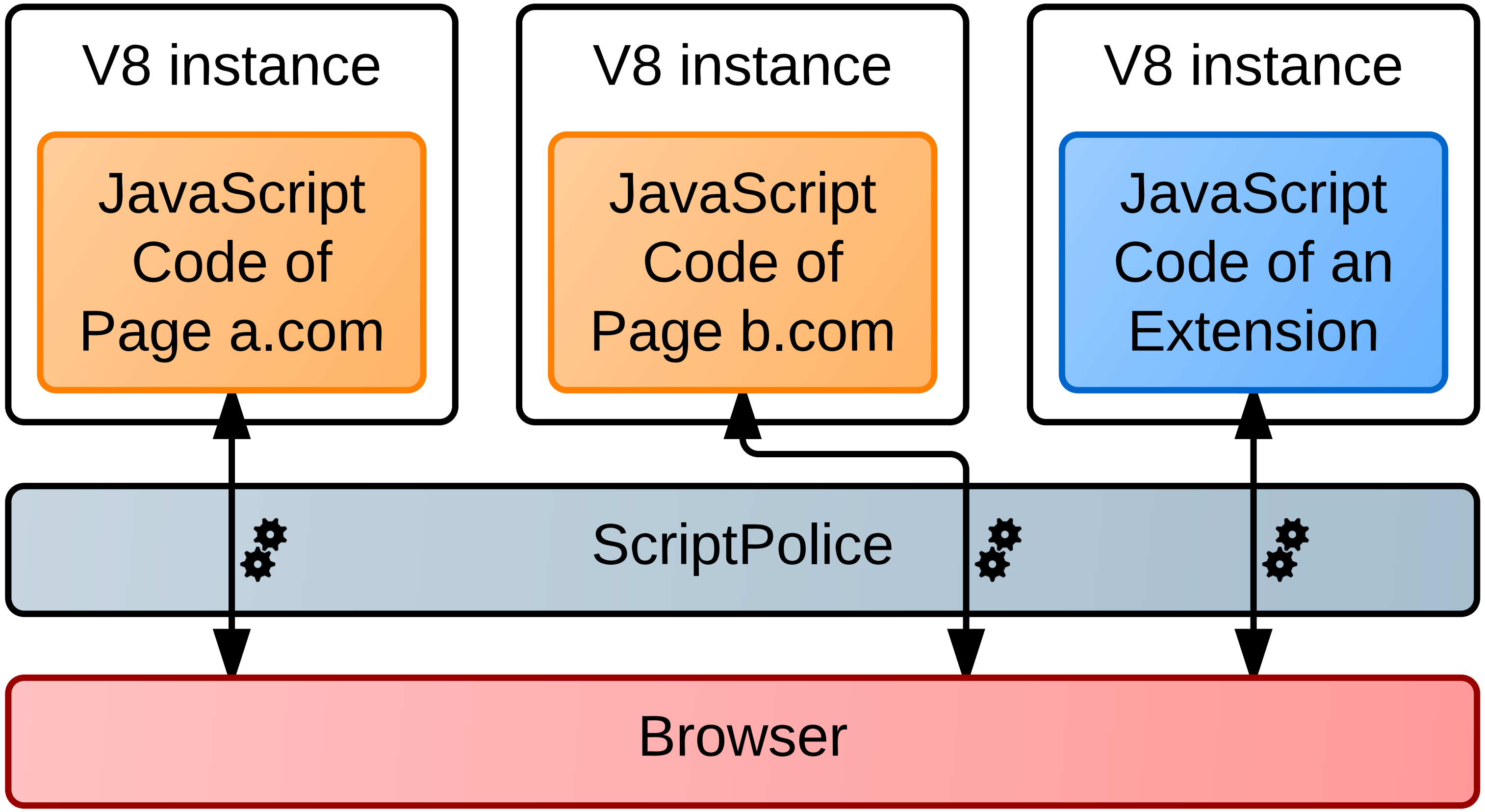
Two key technical contributions:

Run-time code specialization of IFC in V8 JIT compiler yields high performance

Discretionary access control at sinks yields broad policy applicability

by an extension with enhanced extension manifest

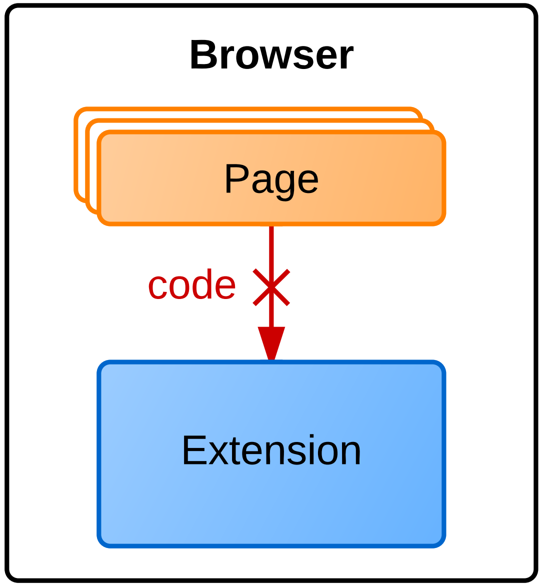
ScriptPolice: Interposition



– policy decisions: allow, block, throw exception

Prevention Policy

- Prevents pages from injecting code into vulnerable extensions
- Implemented with object-granularity IFC for JavaScript
  - Label all page data inbound to extension's V8 environment as `<page-origin>`
  - Propagate labels during JavaScript execution
  - Throw exception upon execution of code labeled `<page-origin>`
- IFC for preventing script injection not new [Djeric and Goel 2010]
- Our contributions:
  - **JIT-compiled** IFC for JavaScript
  - Faster IFC through **run-time specialization**



High-Performance IFC: Specialize for Non-Labeled Data

- Previous dynamic, fine-grained IFC systems (e.g., taint tracking) emit label propagation code for every operation

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  Set(label_flag);
r = a1 + a2;
if (IsSet(label_flag))
  Label(r, Labels(a1, a2));
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High-Performance IFC: Specialize for Non-Labeled Data

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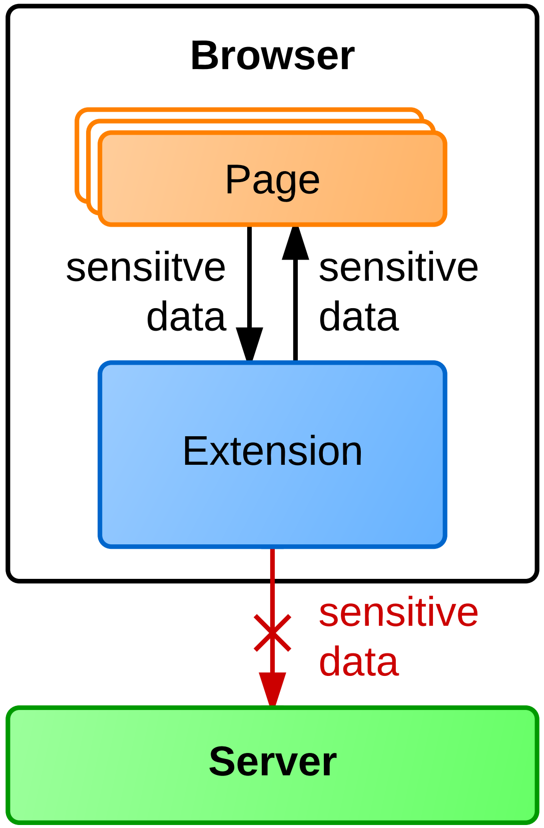
Only pay overhead when processing labeled data; non-labeled execution at full speed!

Containment Policy

- Defends pages against malicious extensions
- Blocks exfiltration of sensitive information via network
- Implemented with discretionary access control (DAC) for V8 JavaScript environment
  - Key idea: as needed, apply DAC at the data sink (browser-network boundary) or at the data source (page)
  - Benefits: no implicit flows, generality, simplicity
- Our contributions:
  - DAC policies widely compatible with canonical extension behaviors
  - Automatic policy selection for extensions based on manifest



Challenge: DAC for Legacy Extensions

- Naïve approach: deny extension access to all DOM elements marked sensitive in page
  - Definitely prevents exfiltration of sensitive data by extension—never sees such data
  - But breaks many extensions that must compute over sensitive data to do their job, and never even try to exfiltrate sensitive data!
  - Subtle conflict of interest: page author can mark data "sensitive" to deny extension access! (e.g., ads invulnerable to AdBlock…)
- Insight: need more flexibility than source-based DAC provides

Canonical Extension Behaviors

- Local behavior: read from page, process locally, display result; no network communication (e.g., FlashBlock)
- Remote behavior: read from page, send to remote server for processing, display result (e.g., Google Dictionary)
- Promiscuous behavior: read from page, send to remote server unknown at extension installation time, display result (e.g., Download Master)

Canonical Extension Behaviors

- Local behavior: read from page, process locally, display result; no network communication (e.g., FlashBlock)

Observations and a caveat:

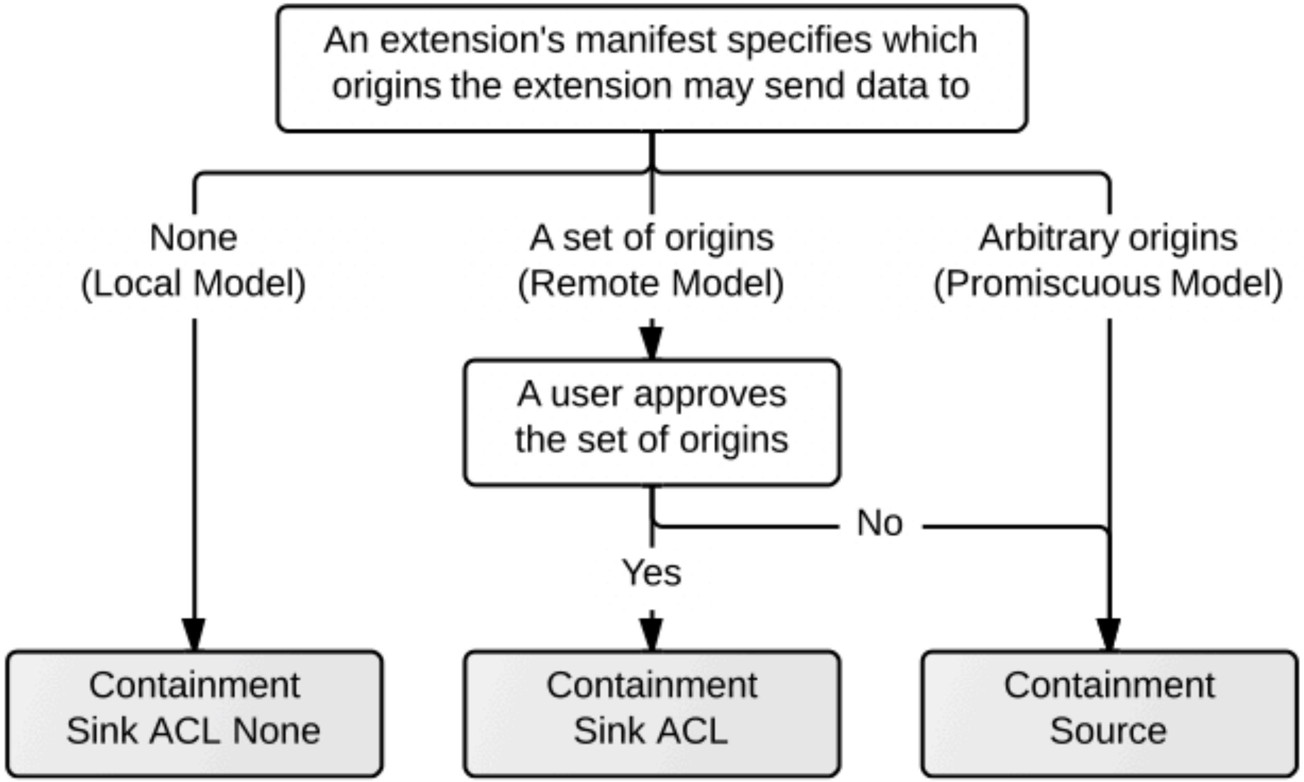
Local extensions don't need network access

Remote ones do, so risk exfiltrating sensitive data from pages

Covert channels excluded from threat model **for now**

(e.g., Download Master)

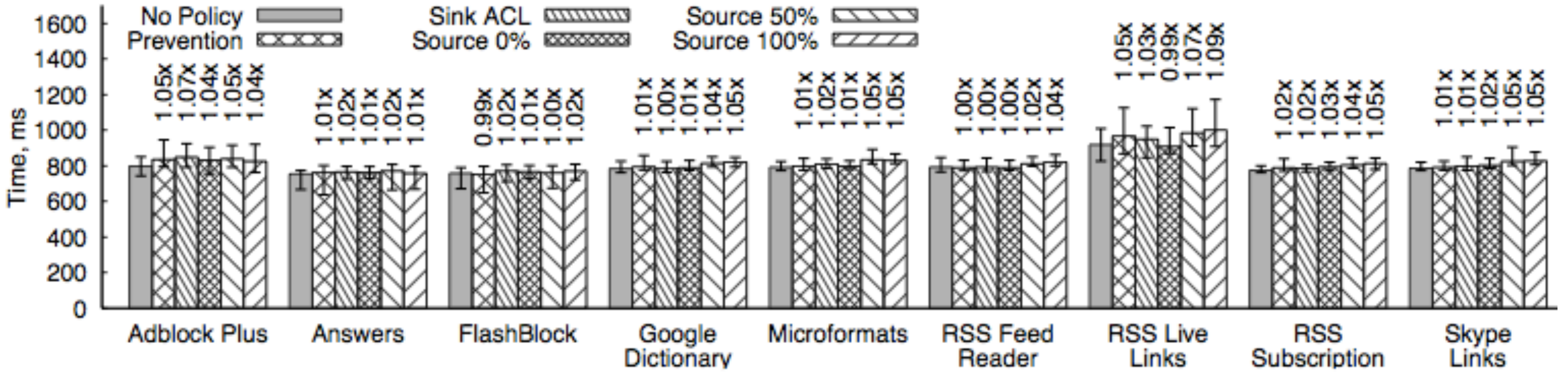
Flexible Containment: DAC Sink and Source



Evaluation

- Implemented ScriptPolice for V8 JIT-compiled JavaScript environment in Google Chrome browser
- Evaluated with dozens of extensions and Alexa top-100 web pages
- Metrics:
  - Browser performance: users essentially unwilling to "pay" much for improved confidentiality
  - Policy compatibility with legacy extensions (i.e., don't break them)
  - Policy efficacy at preventing {injection, exfiltration}

ScriptPolice Is Fast: YouTube Page Load Latency



- Page load latencies are for 25th %ile, median, and 75th %ile over 100 trials
- For most extensions and pages, ScriptPolice increases page load times over baseline by less than 5%, on the order of tens of ms
- Results for other pages and extensions broadly similar

Next Step: Principled Whole-Browser Security with IFC

- Ad hoc, porous implementation of SOP is root of browser vulnerability misery: XSS, CSRF, third-party image/CSS leaks, &c., &c., &c.
- Observation: the SOP is a non-interference IFC policy, but patchily implemented
- Our ongoing work: replace the SOP with pervasive, browser-wide IFC, including exposure of labels to JavaScript code:
  - Stronger isolation than ad hoc SOP
  - More flexible than SOP for, e.g., mashup creation

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In discussions with Google Chrome and Mozilla Firefox developers about adoption

To learn more, read our HotOS 2013 paper (appearing next week!), available at:
http://www.cs.ucl.ac.uk/staff/B.Karp/

exposure of labels to JavaScript code:
  - Stronger isolation than ad hoc SOP
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ScriptPolice: Summary

- Today's browsers don't protect sensitive data robustly, because SOP doesn't (and cannot) constrain extensions
- Prevention and containment: two general policies that protect sensitive data in browsers
- ScriptPolice: practical policy system for V8 JavaScript engine in Chrome browser [code release imminent!]
  - General: supports Containment and Prevention policies for wide range of extensions and pages
  - Fast: native-code IFC; negligible overhead per page load
- Key new techniques:
  - Tailoring DAC Source/Sink to canonical extension behaviors
  - Run-time specialization for fast JIT-compiled IFC